Application of a GIS-based Groundwater Vulnerability Assessment in a Participatory Process

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1. Introduction
The European Water Framework Directive (WFD) came into force in December 2000 and demands for a good status of all European waters by the year 2015. To achieve that objective, the WFD provides for a Programme of Measures in article 11. The research project PartizipA at the Institute of Environmental Systems Research (University of Osnabrück, Germany) supports regional stakeholders in the Hase river catchment in Northern Germany to select groundwater protection measures. The project has been carried out besides the official implementation process of the WFD; hence, decisions made in the project’s participation process have no legal commitment for the stakeholders.

A vulnerability assessment approach for the groundwater in the study area is presented which takes into account diffuse nitrogen emissions of agriculture as well as the groundwater pollution potential and the stakeholder judgement of the regional adaptive capacity.

After a description of the study area in section 3, the methodological approach of the vulnerability assessment is outlined in section 4 and includes a short description of the two applied models STOFFBILANZ and DRASTIC. Section 5 refers to the use of GIS and models in the PartizipA project and is followed by a summary of the most important experiences out of the project concerning model application in the participatory process in section 6.

2. Main objective of the research
The aim of the study was to evaluate the vulnerability of groundwater in the Hase river catchment. Measures conducted at highly vulnerable areas are supposed to be most efficient. In that way, the WFD’s demand for cost efficiency of measures (article 16) is met. The vulnerability assessment should support the spatial allocation of groundwater protection measures. Moreover, the efficiency of groundwater protection measures should serve as basic information for the measurement planning in the participatory process.

3. Study area
The Hase river catchment is a sub-catchment of the river Elbe in Northern Germany and covers an area of 3000 km². The river Hase has a length of 170 km and belongs to the county districts of Osnabrück, Vechta, Cloppenburg and Emsland in Northern-Saxony as well as to the county district of Steinburg in North Rhine-Westphalia. 68% of the catchment area is agricultural land. The county districts of Vechta and Cloppenburg are the most important regions in Germany for pig and poultry production; the five county districts of the Hase river catchment are the ones with the highest pig density in Germany. With 4.7 million pigs 20% of all German pigs are kept in this region (Klohn/Windhorst 2003). The mean value of livestock density in the region is 2.1 livestock units per hectare; the maximum value is 3.9 livestock units per hectare (average for Germany: 0.9 livestock units per hectare).

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4. Methodological approach

Given the fact that the Hase river catchment is characterised by intensive livestock husbandry, the investigation focuses on diffuse nitrogen emissions deriving from animal farming and being washed out into groundwater. In order to identify sensitive areas, a vulnerability assessment of the groundwater in the study area is conducted.

One objective of the vulnerability assessment was the integration of the adaptive capacity and thus not only to assess nutrient flows to groundwater but also to assess the human capability to mitigate groundwater pollution. To this end, the concept of recent Climate Change Research has been adopted in this study, describing vulnerability as a function of the three elements exposure, sensitivity, and adaptive capacity (IPCC 2001, 89).

In the study presented here, the STOFFBILANZ model is used to calculate nitrogen emissions of agriculture (exposure). It is combined with the DRASTIC model which defines an index of the groundwater pollution potential without taking into account the current land use. DRASTIC was developed by the U.S Environmental Protection Agency in 1987 (Aller/Bennet/Lite/Petty/Hackett 1987) and is freely available. Using the measurable parameters of the index, the sensitivity of groundwater is spatially explicit computable and can be integrated into the vulnerability assessment. The adaptive capacity of the region concerning agricultural nitrogen emissions into groundwater is evaluated in a participatory process, where regional stakeholders made estimations about costs of possible groundwater protection measures in the region as well as about their acceptance by farmers. Adaptive capacity then can be seen as the nitrogen reduction achieved by groundwater protection measures realised on the maximum area which is possible from the stakeholders’ point of view. Figure 1 shows a graphical representation of the above mentioned vulnerability assessment approach.

4.1 STOFFBILANZ

One of the models we used is the nutrient model STOFFBILANZ, which was developed at the Technical University of Dresden (Gebel/Grunewald/Halbfaß 2005). The model’s concept takes into consideration the demands of the WFD (Kunst/Scheer/Panckow 2003). It is based on an Access database and works on polygons as well as on grid cells. The STOFFBILANZ model consists of the modules N-balance, Data storage N-balance, Water balance, Soil erosion and P-balance. In this paper, I focus on the nitrogen part of model being the most relevant factor for the investigation area. STOFFBILANZ connects the above mentioned modules with the aim of calculating nutrient emissions of diffuse sources. The input data for the model are soil type, geology, elevation, climate, land use, and animal density. Model outputs are nitrogen emissions from diffuse sources separated into the runoff paths surface runoff, interflow, drainage runoff, and groundwater recharge. Furthermore, nitrogen concentrations in the seepage water and nitrogen emissions in the receiving stream are calculated.

Data generation for the STOFFBILANZ model is completely done in ArcGIS, the reclassification of data according to the model requirements and their transformation to the 500x500 meter grid being the most important work steps. Data are exported to the Access database of the STOFFBILANZ model and re-imported to ArcGIS for a visualisation of the model results after the model run.
Sensitivity
DRASTIC
Adaptive capacity
Groundwater
protection measures
(participatory process)

Input parameters:
- Depth to water
- Recharge
- Aquifer media
- Soil media
- Topography
- Impact of the vadose zone media
- Conductivity

Selection of groundwater
protection measures
Estimation of
- Costs
- Acceptance by the farmers

Possible spatial extension

Stakeholder
judgement of
regional
adaptive
capacity

Spatially explicit
vulnerability map
Analogue GIS map

Exposure
STOFFBILANZ
Nitrogen emissions
(reference scenario)

Efficiency of measures
(nitrogen reduction)
- $m_1$
- $m_2$
- …
- $m_i$

Nitrogen emissions
(groundwater
protection
measures)
- $m_1$
- $m_2$
- …
- $m_i$

Fig. 1: Vulnerability assessment approach in the study

5. GIS and models in the participatory process

Stakeholder participation in the Partizipa project was organised as an actors’ platform, which was composed of 14 representatives of regional organisations, who are involved in the implementation process of the WFD. The organisations cover the sectors agriculture, water management, forestry, nature conservation, and administration. From October 2003 until May 2006 seven afternoon meetings took place. The specific main topics of the seven meetings were as follows:

Meeting 1: Kick Off Meeting
Meeting 2: Introduction to the WFD, results of the WFD Article 5 Report for the Hase river catchment
Meeting 3: Discussion of cognitive maps of the stakeholders concerning nitrogen load in the study area
Meeting 4: Discussion of measures focusing on the topics agriculture and consumer behaviour
Meeting 5: Introduction to the STOFFBILANZ model (model structure)
Meeting 6: First results of the STOFFBILANZ model (reference scenario and measures)
Meeting 7: Decision about a final document (“Schlusdokument”) of the actors’ platform containing the groundwater protection measures recommended for the Hase river catchment

Due to time constraints, the model presentation concentrated on STOFFBILANZ, whereas the DRASTIC model was not discussed within the actors’ platform. The STOFFBILANZ model was integrated in two sessions. In meeting 5, the model structure including input variables, basic equations, and output variables was presented. Further, the input variables for the reference scenario “Current land use” were discussed.

\footnote{For document download see \url{http://www.partizipa.uni-osnabrueck.de/dokumente.html}}
with the stakeholders. The input variables defined in this meeting, particularly concerning fertilization and yields in the study area, were used to compute a first version of the reference scenario. In meeting 6, model results of STOFFBILANZ (for the reference scenario as well as for three land use change measures) were presented using analogue GIS maps, to check their correspondence with the stakeholders’ experiences from practice. While GIS in the modelling process is used for data generation and conducting map algebra, it is more relevant for the stakeholders as a visualisation and communication tool.

6. Conclusions

In the PartizipA project model application in the participatory process has been designed as an iterative participatory procedure with stakeholders. Hence, provisional model results coming from work in progress have been presented to the stakeholders, who had little confidence in these provisional results and desired for complete and validated model results. Moreover, scale problems were identified within the participatory process: While the WFD prescribes to investigate the nutrient load on catchment scale, the stakeholders refer to much more detailed scales of single fields. As a consequence, the participants of the actors’ platform had wide difficulties to translate the model results calculated on catchment scale to their local level and perceived the model’s results as too broad.

From the PartizipA project the conclusion can be drawn that an expert tool such as the nutrient model STOFFBILANZ is not adequate for an immediate application in the participatory process. An indirect model use is proposed, where the expert model is run without stakeholder interaction, but aggregated model results are presented to the stakeholders. Furthermore, for the acceptance by the stakeholders an appropriate visualisation of the model results is very important.

Bibliography


